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GOOD PRACTICE GUIDE 272

Lighting for people, energy efficiency and architecture

– an overview of lighting requirements and design

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

CONTENTS

1 INTRODUCTION

Energy efficiency and sustainability are important issues of modern life to ensure a continuing and improved environmental quality for all. This Guide to lighting requirements and design is produced as part of the Government's Energy Efficiency Best Practice Programme.

Lighting is an essential part of all our lives but it consumes large quantities of energy if not designed well. But to consider energy efficiency without seeing it in the context of the total design could lead to lit environments that are perhaps inappropriate, uncomfortable or unpleasant, all of which could lead to poor human productivity. Hence an approach to lighting design is necessary which considers all the requirements and constraints – a holistic design.

This Guide provides an overview of lighting design touching on both daylighting and electric lighting. It does not provide detailed design guidance but aims to describe the issues that need to be addressed. It is aimed at designers and installers of lighting but it will also be of value to building users and providers to enable them to appreciate what needs to be included and why. It describes the main lighting concerns for most applications, but for some specialist situations others may need to be introduced. The information applies to new and refurbished buildings, although the solutions may be different depending on the constraints.

Often the approach to lighting design is limited to task illumination and where this is the case valuable benefits are lost. These include benefits of environmental quality and efficiency that can lead to increased human effectiveness. This Guide aims to overcome these limitations and to help people towards better lit environments. The reader is encouraged to read the complete document at least once, then to return to parts of it as required.

2 A HOLISTIC APPROACH TO LIGHTING DESIGN

Light, because it enables us to see, is probably *the* most important form of energy in man's existence. Not only does it enable us to do the myriad of visual tasks demanded by everyday life, but it can also affect our health, our mood and our mental stimulation. Hence it can affect our way of life and our productivity.

But what is light? It is energy, which is either generated naturally by the sun providing daylight or by the conversion of electricity into light by electric lamps, but whichever way it is generated it provides us with the power of sight. It gives us a communication pathway from the world around us to our brain. Since sight is by far the greatest provider of information, lighting is an important aspect of any environmental design.

A successful lighting scheme, whether it is daylighting or electric lighting, or as is more usual, a combination of the two, needs to satisfy a number of often conflicting requirements. This means considering each of the requirements against the constraints – balancing one against the other until the best solution emerges. To facilitate this process the 'lighting design framework' is provided, as illustrated in figure 1. It can act as an aide-mémoire to ensure that nothing is overlooked. It contains the following six elements, although others may need to be introduced for particular applications:

- visual function
- visual amenity
- architectural integration
- energy efficiency
- installation maintenance
- costs (capital and operational).

Together these elements cover lighting the task, the lit appearance of the building, and the energy efficiency and economics of the installation. For a particular building the elements may not carry equal weight, nor do they need to be considered in any particular order, but they all need to be considered, perhaps more than once, for a successful solution to result.

The following sections examine each of the design elements in turn, indicating the fundamentals of what needs to be considered and how they need to be integrated within the overall design.

Figure 1 Lighting design framework

3 LIGHTING FOR VISUAL FUNCTION

LIGHT AND SIGHT

In any environment it is essential that people can see 'well' to do their particular tasks. These will vary depending on the application and will often include more than one. They could range from moving safely around a building to carrying out a demanding visual task, such as the manufacture of electronic equipment or surgical work in an operating theatre. Face-to-face communication between people is important, for example, in places like schools, shops and offices, while good surface colour appreciation and recognition are important in museums, shops, and some factories.

Although people can see over a wide range of different brightness levels, they can only see 'well' when there is sufficient light for the task and when the brightness range within the field of view is limited. For example, people can read a newspaper headline under bright moonlight, or under bright sunlight but if the newsprint is small then the moonlight will be insufficient. The eye, at its most simplistic, can be compared to a camera with an automatic exposure setting, in that it will automatically adapt to the general level of ambient light. If the light level changes, as when moving from a bright area to a dim area or vice versa, the eye will take time to readapt. For a particular level of adaptation the eye can only cope with a limited range of brightness for good and comfortable visibility. If the brightness range in the normal field of view is too large, then from bright sources there will be glare, which will cause visual discomfort or disability, but in very dark areas it will be difficult to see, as shown in figure 2.

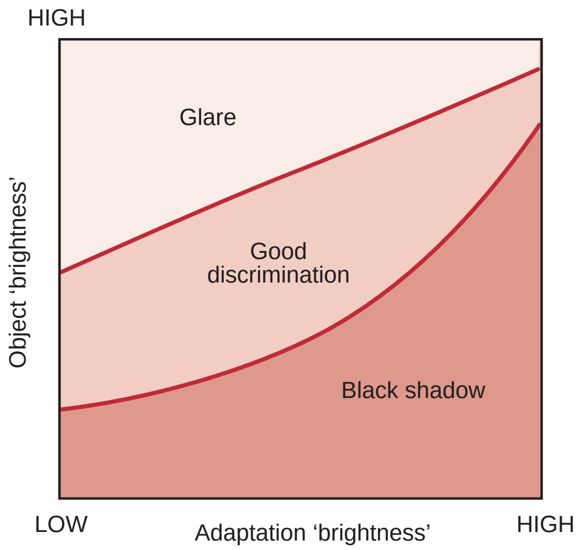

Figure 2 The general effect of visual adaptation and object brightness on visual discrimination

A light level on a surface is described by the term 'illuminance' and is measured in lumens/m^2 or lux. This defines the amount of light energy in lumens divided by the surface area in square metres.

People see things either through a brightness or colour contrast, or sometimes both, and the lighting needs to help this process. For example, when reading a book the light illuminates the white paper showing the black text in contrast. For inspecting a textile, the light needs to show off both the texture and the colours of the fabric accurately so that any faults can be identified. When using a computer, because it contains its own light source, no additional light is required, in fact if light falls on the screen and it reflects back into the user's eye, then this can cause glare which can reduce visibility. Light will, of course, be required on the computer keyboard and in the surrounding area.

TASK ILLUMINANCE AND ILLUMINANCE UNIFORMITY

Task illuminance, or more correctly the maintained illuminance, is the amount of light that people need to see well for a particular type of task. The term 'maintained illuminance' is used to define the minimum task illuminance that can occur before some maintenance of the lighting installation needs to take place, and this is usually used as the design illuminance. The actual level will depend on the visual difficulty of the task, the age and the quality of the person's sight and the degree of accuracy of performance necessary.

Figure 3 indicates the general relationship between performance, illuminance and task difficulty. It shows that as illuminance increases, performance also increases until a near static level is reached. It also shows that simple and difficult tasks have different levels of performance.

Table 1 lists a number of typical tasks together with their recommended illuminance for people with normal vision. This has been taken from the CIBSE 'Code for interior lighting'[1], commonly known as 'The Code', which provides further information.

The distribution of light across the task area needs to be as uniform as possible. There is, however, some evidence to suggest that highlighting the immediate task area can enhance visibility, hence often the stated preference for task lights or desk lights. Task area highlighting is particularly useful when high levels of task illuminance are required.

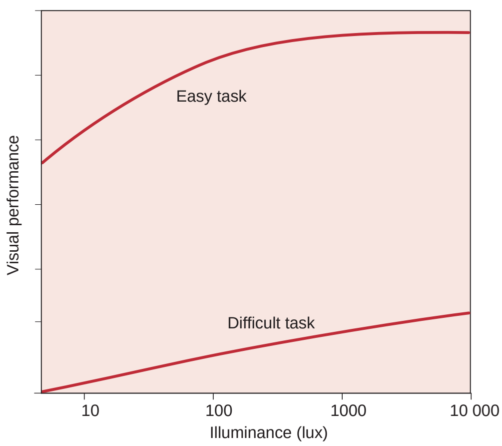

Figure 3 Schematic diagram indicating visual performance with respect to task difficulty and task illuminance

For a room where the tasks are to be carried out anywhere in the space then there may be a case for providing the task illuminance over the whole area. However, there can be benefits in both performance and efficiency by providing the task illuminance only where required and providing a lower value in the circulation areas. But the overall degree of benefit will be determined by the lighting system employed and how it is to be controlled.

GLARE

If a bright light source occurs in the normal field of view, either directly or by reflection, it is likely to cause at least distraction, possibly visual discomfort or, in extreme cases, visual disability. To guard against this, it is necessary to minimise or exclude all bright sources from the normal and reflected field of view, as illustrated in figure 4.

This applies to lamps, luminaires and to windows, which may need blinds, particularly on sunny days. There is an internationally agreed glare index system, which provides a numerical grading of different electric lighting systems together with recommendations for different applications. Details of this system are given in the CIBSE Code[1].

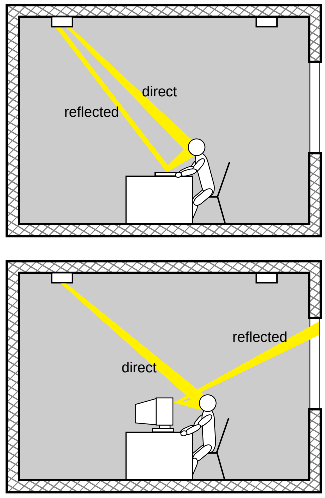

Figure 4 Possible sources of direct and reflected sources of glare

Example task/application	Recommended task illuminance (lux)
Circulation areas (corridors, stairs, lobbies)	100-200
Offices (reading, writing, computer use)	300-500
Industrial (assembly, manufacture, testing)	300-2000

Table 1 Indication of task illuminance for a number of typical tasks for people with good vision taken from the CIBSE Code[1]. Note an illuminance range is shown because the exact illuminance required will depend on the difficulty of the task

Reflected glare can be a problem when light reflects off the work piece, which might be a piece of metal in a workshop, a computer screen or a glossy book. This can be avoided by eliminating any bright source in the area which can be seen by reflection in the work – as shown in figures 4 and 5.

FLICKER

Light flicker from discharge lamps, eg fluorescent tubes, operating on a normal 50 Hz mains electricity supply, can be both annoying and uncomfortable to some occupants. In extreme cases it can cause headaches and stress. This can be overcome by using lamp control gear circuits that operate the lamps at high frequency, usually at around 30 kHz, which has the added advantage of improved energy efficiency. These circuits can also incorporate the opportunity to adjust the light output (dimming). This is often appreciated by the users and can further increase energy efficiency by people only using the amount of light they require.

LAMP COLOUR RENDERING AND APPEARANCE

The colour performance of a light source needs to be considered with respect to the task and to the appearance of the room. This is because different electric light sources have different performances. Some show surface colours accurately, while others can distort surface colours with disastrous effects, particularly where colour matching or identification is important, such as in a factory or shop. This effect is described by the term 'colour rendering', which for lamps can be described by a general colour rendering index (Ra). This index uses a scale where the lower a lamp's Ra value relative to an 'excellent' value of 100, the poorer the lamp's colour rendering ability. The internationally agreed scale is shown in table 2.

Typical application	Colour rendering groups	CIE general colour rendering index (Ra)
Very accurate colour judgement (inspection)	1A	90 and above
Accurate colour judgement (shops and offices)	1B	80-89
Moderate colour judgement required	2	60-79
Low colour judgement without marked distortion	3	40-59
Colour rendering of no importance	4	20-39

Table 2 Indication of required lamp colour rendering performance for different tasks. Further details are available in the CIBSE Code[1] or from lamp manufacturers

Figure 5 University computer workstation facility lit by local lights which avoid reflected glare, and the light is directed to where it is needed with a reduced power density

The colour appearance of a lamp refers to the apparent colour of the light emitted, or the colour appearance of a neutral-coloured surface illuminated by it. It is described by the term 'correlated colour temperature' (CCT) which is measured in Kelvin and relates to the colour appearance on a scale of 'warm' to 'cold'. Table 3 shows the relationship between colour appearance and CCT. It is usual, in rooms that receive some daylight and require electric light to complement it, to use lamps with a CCT of around 3500-4000 K. If, however, a more domestic atmosphere is required, then a lamp with a warm appearance (eg an approximate CCT of 3000 K) will be necessary (see figure 6).

Colour rendering and appearance criteria are independent of one another, and lamps with good colour rendering are available in most values of CCT. Further information on lighting for visual function is given in the CIBSE Code[1].

Application examples	Correlated colour temperature class	Correlated colour temperature (K)
Residential and similar	Warm	3300 and below
Where electric lighting needs to complement daylight	Intermediate	3300-5300
Where cool/cold appearance lighting is required	Cold	5300 and above

Table 3 Indication of lamp colour appearance with correlated colour temperatures. Further details are available in the CIBSE Code[1] and from lamp manufacturers

Figure 6 This supermarket is lit with fluorescent lamps with a colour rendering index of over 80, and because the lighting is fitted to the display shelves the effectiveness and energy efficiency are also very good. Note the effect of the indirect lighting mounted on top of the display shelves

4 LIGHTING FOR VISUAL AMENITY

The way an interior is lit, along with the form of the space, and its surface materials and colours, will affect the visual quality of the space, contributing to the interior design and its level of pleasantness. It can also help to create the right atmosphere and degree of visual stimulation for the particular application. This element of lighting will enhance the occupant's feeling of 'well being', which in turn will enhance performance, perhaps not directly, but through such factors as improved motivation, comfort and health.

Very often electric lighting installations are designed to provide good task illumination with little or no account taken of the lit appearance of the space. For example, ceiling-mounted luminaires are often used that direct most of their light onto the horizontal working plane. These can make the overall lit space appear gloomy and underlit even though the task illumination is suitable.

Research has shown that in general, people prefer a space to appear 'visually light' and to be 'visually interesting'. What this means in design terms is that the space needs to have some illuminated surfaces, particularly vertical surfaces which form the main part of the normal field of view, but that the ceiling also needs some light, particularly in large rooms. The term 'visual interest' refers to the preference for a variation in the light pattern –

Figure 7 Building under sunlight and under an overcast sky demonstrating visual amenity

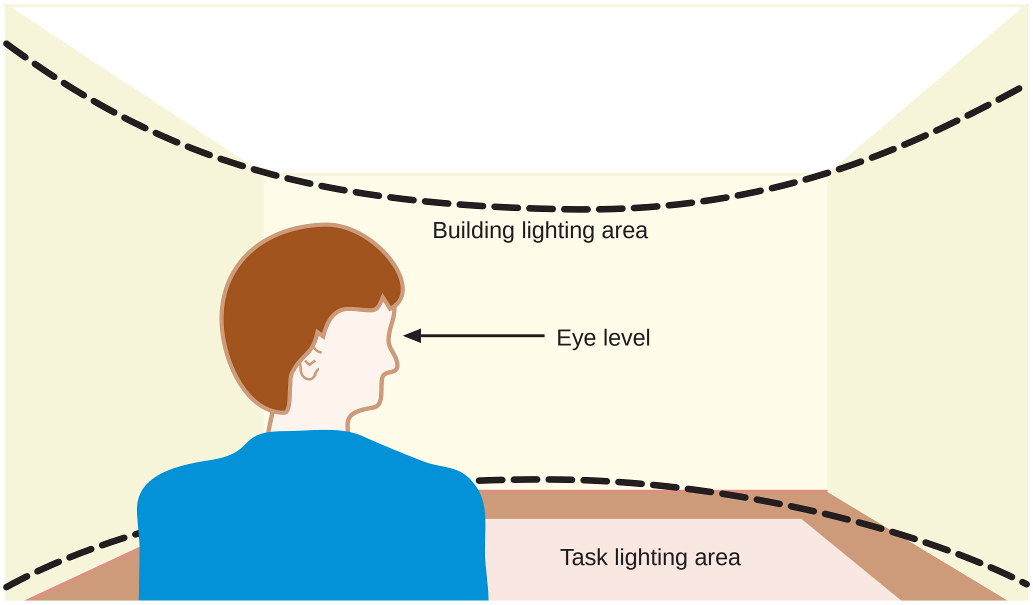

Figure 8 Schematic diagram showing the task and building lighting areas for an office

areas of light and shade. In general people do not like the bland uniformity provided by many installations. People also vary in their illumination requirements even to the extent of liking to be able to adjust the light during the day. These preferences for lighting beyond the working plane are reflected in people's preference for daylight with some sunlight to lighting from a cloudy, overcast sky, as shown in figure 7.

A way to approach amenity lighting is to consider it as 'building lighting' as opposed to 'task lighting'. The two zones, for an office-type situation where the main task is on a horizontal surface, are shown in figure 8.

It must be recognised that visual lightness cannot be achieved by light alone. To achieve a 'light'-appearance surface, or space, it will be necessary to use a combination of direct illuminance and a high-reflectance surface. As a general guideline, for work interiors such as offices, the average illuminance on vertical surfaces in the 'building lighting zone' needs to be around 200 lux, and the reflectance of this zone needs to be not less than 0.5 or 50%. With regard to visual interest, a variation in vertical illuminance of between 3:1 and 5:1 in the building lighting zone will provide visual interest without the pattern being over-dramatic. The transition from bright areas to less bright areas will also need to be considered – should they appear dramatically different or should they blend softly from one to another? Figure 9 illustrates schematically the relationship between visual interest and visual lightness for different applications.

These guidelines provide only an indication of what is required – the designer needs to explore various light pattern possibilities to achieve the effect required for the particular application. Sometimes the task and building lighting can be provided from just one lighting system, but often at least two systems are necessary for a successful overall solution. For example, some form of wall-washing lighting, or uplighting onto the ceiling may be required to create the desired building lighting effect (see figures 6 and 10).

Amenity lighting must also be meaningful to the use and appearance of the building and to its architectural design. It is therefore important to identify which areas and objects need to, or can be lit so as to create an appropriate light pattern which is a natural extension of the architecture. For the best result the lighting designer will need to work closely with the architect and the client.

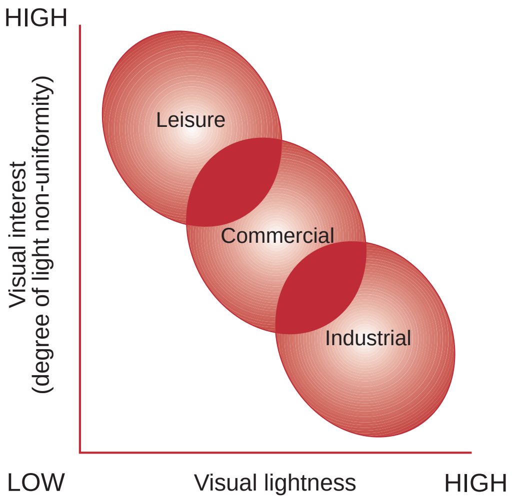

Figure 9 Schematic diagram showing the relationship between visual interest and visual lightness for different applications

Figure 10 This shopping mall is lit by daylight and electric light, and they both aim to create a light and interesting light pattern

5 LIGHTING AND ARCHITECTURAL INTEGRATION

Both daylighting and electric lighting should be considered natural extensions of the architecture, and not just as something installed to enable people to see their task, although of course this is important.

For daylighting, this means considering the amount and pattern of daylight, and hence the size and position of windows and rooflights. But windows cannot be designed on the basis of daylight alone, and other environmental issues need to be addressed. These include the outside view, and sun penetration with respect to glare and solar gain. Windows can also provide natural ventilation, but thermal and acoustic insulation may also need to be considered. People generally prefer to live and work in daylit buildings, and every effort should be made to provide for this, but, like electric lighting, daylighting needs to be designed in a structured way. Both the lighting design framework, and Good Practice Guide 245 ‘Desktop guide to daylighting – for architects’ (see page 22), should help this process.

Once the daylighting has been designed, then the electric lighting needs to be designed to complement the daylight when necessary and to take over from it when the daylight fades. This will mean considering it in zones relative to the daylight distribution – without this there will be a tendency for the lights to be on all the time.

Figure 11 Electric lighting installation where the luminaires are integrated into ceiling vaults

It will also include the use of both manual and perhaps automatic lighting controls to avoid the unnecessary use of electric light when there is sufficient daylight.

To integrate the electric lighting with the architecture means considering, not only its operation with respect to daylight, but the appearance of the lighting equipment and the way it is incorporated into the building fabric, as well as the lighting effect. Just as the light pattern needs to be meaningful with respect to the building use, the lighting scheme needs to be meaningful with respect to the architecture, including its style.

Many electric lighting installations are fitted directly onto the ceiling surface. Although this has the tendency of making the ceiling look cluttered, it can provide a generally light appearance if luminaires with both upward and downward light output are used. Luminaires suspended from the ceiling can have a similar effect, but if they relate to ceiling coffers or vaults then a more co-ordinated effect will result, as illustrated in figure 11.

On the other hand, ceiling-recessed luminaires give a tidier appearance, but they are likely to provide a less ‘well lit’ spatial appearance, particularly if they have a tight optical control using specular louvres. This effect can be reduced when ceiling-recessed luminaires are used that have their own integral coffer, as shown in figure 12.

Figure 12 Electric lighting installation using ceiling-mounted luminaires which provide both uplight into the ceiling coffers and downlight onto the work area

The effect of dark walls can be overcome by including wall-lighting equipment, either linear systems using tubular fluorescent lamps, or individual luminaires perhaps using compact fluorescent lamps (CFLs). If linear systems are used then they need to form an integrated part of the wall or ceiling, as illustrated in figure 13.

Spotlights can provide accent lighting to highlight areas or objects, but again the pattern needs to be relevant. For example, the pool of light from a single spotlamp needs to illuminate a specific object such as a picture, a commercial display or plants for it to be meaningful.

If a number of spotlights are used in a line to illuminate a wall, then the resulting scallop pattern must be appropriate. For example, it might be used to enhance the appearance of a textured surface, as shown in figures 14 and 15.

If the luminaires are visible, then their appearance needs to fit in with the overall style of the building. Even where luminaires are used mainly as decorative elements, their lighting performance must also be considered.

This consideration does not only apply to the building lighting but also to the task lighting, particularly when this is provided separately. This means considering whether the task lighting is to be attached to the building in a traditional sense, or to a workstation, such as a desk light. It could, alternatively, be floor-standing, providing both task and building lighting, as shown in figure 16. The way in which the organisation operates also needs to be considered – for example, does it use cellular or open-plan spaces? Also, if it envisaged that there will be the need to alter the layout of the work areas, flexibility should be built into the design. Planning for change may also involve more extensive alterations, such as removing walls or partitions. If this is anticipated, then adopting a lighting system that avoids installing wiring in or on these surfaces would enable alterations to be carried out inexpensively.

It is difficult to be explicit about lighting design as an integrated part of architecture, as there are many possibilities and considerations. Sadly, lighting is often seen as just a building service that enables people to carry out their visual tasks. Good lighting design is, however, fundamental to the design of a building, and without due consideration valuable opportunities will be lost.

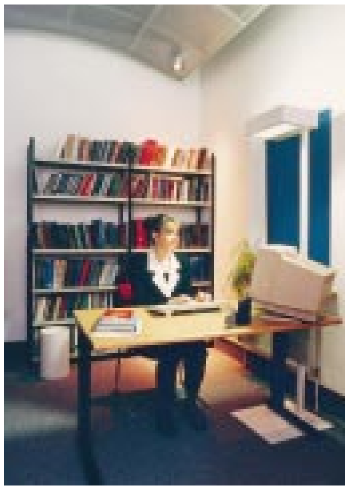

Figure 16 Trial installation using portable floor-standing luminaires incorporating task and building lighting

Figure 13 Wall and ceiling illumination by architecturally integrated lighting components

Figure 14 Lighting is used in this retail example to add emphasis to the products and to the building surfaces

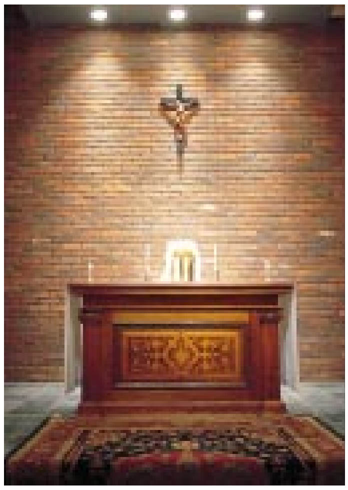

Figure 15 Downlights used to create a light accent to draw attention to the altar and to enhance the wall texture

6 LIGHTING AND ENERGY EFFICIENCY

In the UK, 20% of the electricity generated is used for lighting. This amounts to approximately 58 500 million kWh, or units of electricity, and to 34 million tonnes of carbon dioxide (CO_2) emissions each year. Of this, approximately 58% is used in the service sector (offices, shops, warehouses, etc), 13% is used in the industrial sector, and 29% in the domestic sector. These figures are based on BRE's 1994 results (BRE 1994 internal report).

It is therefore essential that all lighting installations are as energy efficient as possible, because this can provide substantial reductions in energy costs as well as helping to preserve the global environment for future generations.

Although energy efficiency is important, it nevertheless has to be seen as part of the overall design framework, as any lighting scheme must provide the users with the necessary lit environment. This is particularly important in working environments where the cost of the workforce is usually by far the most expensive item.

If the building is still at the design stage, then the first thing to consider is the daylighting performance. For a building that is being refurbished, the existing daylight, as well perhaps as the potential for its improvement, needs to be assessed.

Once this has been determined, then consideration can be given to how electric lighting can be used to complement the daylighting, as described in section 5.

LIGHTING CONTROLS

Good controls are essential to energy-efficient lighting. Suitable switching patterns may be all that is needed, or it may be appropriate to use more sophisticated automatic controls such as daylight sensing, which may also include the ability to vary electric light output relative to the daylight. Time switches can switch lights off at convenient times during the day when it is expected that either there will be sufficient daylight in the interior, or that it will be unoccupied. Occupancy sensors can be used to switch lights on or off automatically when people enter or leave a space, although suitable time delays will be necessary to avoid lamps being switched too frequently.

Lighting controls can also provide considerable benefits in terms of human operation. People like to have the opportunity to control their environments, and are often good at switching lights on when they are required but poor at switching them off again when they are not. Lighting should always be switched off when not required, but the pattern of use with relation to the equipment will also need to be considered. For example, it would be pointless to use high-pressure discharge lamps in an area of infrequent use because the lamps take time to reach full light output and will not start, without special circuits, when hot. Fluorescent lamps are often thought to use more energy to switch them on than when operating normally – this is not the case, although constant switching on and off can reduce the life of the lamp. Lamp manufacturers quote the life of fluorescent lamps on the basis of a switching frequency of about eight times in 24 hours. Further information on lighting controls is given in Good Practice Guide 160 'Electric lighting controls – a guide for designers, installers and users' (see page 22).

LAMPS AND LUMINAIRES

Other areas of technology that need to be considered in terms of energy efficiency are lamps and luminaires.

Lamps

Lamps come in many different types, use different techniques for converting electricity into light, and vary in terms of their energy efficiency. A lamp's efficiency is described by its efficacy, or the amount of light produced for the energy consumed, and is measured in lumens/Watt, ie the light output in lumens for the electricity consumed in Watts. Table 4 indicates the order of efficacy for a number of different lamp types, but for exact information individual lamp manufacturers should be consulted.

Luminaires

The next step in the chain is the luminaire. It is pointless to have an efficient lamp if an inefficient luminaire is used. This means using efficient optics (reflectors and refractors) together with efficient lamp control gear, which provide the lighting effect required. A simple measure of a luminaire's efficiency is its light output ratio (LOR). This is the ratio of the luminaire's light output to the light output of the bare lamp, or lamps. It should be noted that this does not indicate the efficiency by which a task illuminance is produced, but it avoids the use of particularly inefficient luminaires. For most situations, a luminaire with an LOR of 0.5 or greater should be used, but to some extent this will depend on the light output distribution required.

Lamp control gear is necessary where discharge lamps are used. This is used to initiate the arc discharge and to control the lamp current. It will also include any power factor correction circuitry. Modern electronic control gear, which operates at high frequency, is typically 30% more efficient than older technologies. This type of control gear can also incorporate light dimming which has the advantage that the illuminance can be adjusted to provide daylight top-up or to suit user needs. It can also be used to provide a constant task illuminance throughout a maintenance cycle. This will avoid over-lighting when the installation is new in order to provide the design illuminance at the end of the maintenance cycle.

During a refurbishment scheme, it will nearly always be beneficial in the long run to replace old and often obsolete equipment with new modern equipment, including lamps, luminaires and controls.

LIGHTING DESIGN

The design of the lighting installation will also influence energy efficiency. For example, if the installation can provide the required task illuminance anywhere in the space, but only part of the space is used for this purpose, then there is a possible waste.

For example, individual workstations in an open-plan office can be lit to the required task lighting conditions while the circulation areas in between can be lit at a lower level (while still taking building lighting into account). Not only has this the potential of being more energy efficient, but it is likely to be preferred by the staff, because it provides a pleasant variation of light and shade.

Lighting energy efficiency needs to consider a number of interrelated topics for optimum performance, but it must be done in the context of the users and the building as a whole, otherwise problems may result. The Energy Saving Trust (EST) offers incentives for improved energy efficiency, and they should be consulted for advice on what is currently on offer – the address is included on page 22.

BUILDING REGULATIONS – PART L

Energy efficiency in lighting is now a mandatory requirement of the UK Building Regulations. This includes a requirement to use mostly high-efficacy lamps and appropriate lighting controls. For details of the requirements refer to CIBSE Guidance Note (GN) 4 'Lighting requirements of Building Regulations Part L'[2].

Figure 17 This office has been lit with fibre optic lighting using metal-halide lamps. Fibre optics are not normally considered to be very efficient, but because the light has been carefully directed to the points of interest, the overall efficiency is good

Lamp type	Approximate efficacy range (lumens/Watt)
Incandescent filament lamps (GLS)	10-15
Tungsten halogen lamps	16-22
Tubular fluorescent lamps	65-95
Compact fluorescent lamps (CFLs)	50-85
High-pressure mercury fluorescent lamps	40-60
High-pressure metal halide lamps	70-95
High-pressure sodium lamps	70-125
Low-pressure sodium lamps	100-200

Table 4 Approximate range of lamp efficacy for different lamp types. For further details refer to lamp manufacturers' data

7 LIGHTING INSTALLATION MAINTENANCE

It must be recognised that both daylight and electric light within a building will depreciate with time, and to minimise this, a maintenance programme will need to be implemented.

DAYLIGHT

In terms of daylight, dirt will build up on the exterior and interior surfaces of the windows. This will reduce the transmittance and therefore the amount of daylight entering the building. The degree to which this will happen will depend on the angle of slope of the glass and the quality of the air environment – an urban area on a busy traffic route will produce more dirt than a rural one. To minimise this problem, windows will need to be cleaned regularly which makes easy and safe access necessary. If cleaning is difficult or hazardous, then it will be expensive, and it will probably not be carried out as regularly as necessary.

Figure 18 This swimming pool has been lit by uplights mounted at the side of the pool. This means that they are easy to maintain, but the lighting also fits admirably with the architectural form of the roof

The interior daylight illuminance will include an amount which is reflected from the internal building surfaces, and to maintain this, the surfaces will need to be cleaned or redecorated from time to time.

ELECTRIC LIGHT

The light provided by a lighting installation will also deteriorate with time. This occurs partly because, for most lamp types, the light output reduces with age. The degree to which this happens depends on the lamp type, and the lamp manufacturers should be consulted for more details.

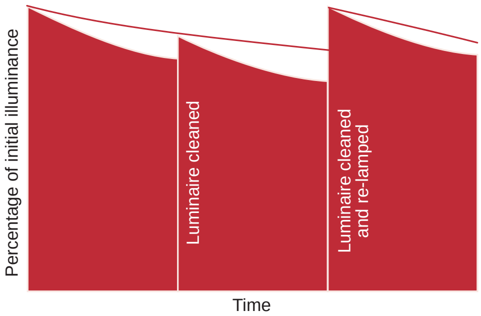

Figure 19 Schematic diagram showing the typical changes in illuminance with respect to time and maintenance

Lamps will also eventually fail, and lamp manufacturers should be consulted about the predicted lamp life. This leads to the question as to whether a user should replace lamps as they fail (spot replacement) or to change all the lamps at a point when it is considered both economic and convenient (bulk replacement). The designer will need to advise the user on the best policy for the particular situation.

Dirt can reduce electric light output just as it can reduce daylight transmittance. Over time, dirt will build up on the optical surfaces of both lamps and luminaires, and, again, a regular cleaning programme will be necessary. The degree to which this will happen depends on such aspects as the type of luminaire, including whether the optics are enclosed, and whether there are upward-facing surfaces which emit light. It will also depend on the surrounding air quality.

To ensure a regular cleaning programme, the equipment needs to be easily accessible. If not, extra-long-life lamps (eg induction lamps) in enclosed luminaires should be considered.

It will also be necessary to clean or redecorate internal room surfaces to maintain the designed level of reflected light.

A further consideration is that some equipment may need to be repaired or ultimately replaced.

MAINTENANCE PROGRAMME

It can be seen that there are a number of different reasons why daylight and electric light output will deteriorate over time. For electric light this is shown in figure 19. These factors need to be considered at the design stage and the client made aware of their implications and costs. This means that a programme of maintenance needs to form part of the design and preferably, that the client should be supplied with a maintenance schedule. Unless this happens, the lighting installation will deteriorate and both energy and money will be wasted.

8 LIGHTING COSTS (CAPITAL AND OPERATIONAL)

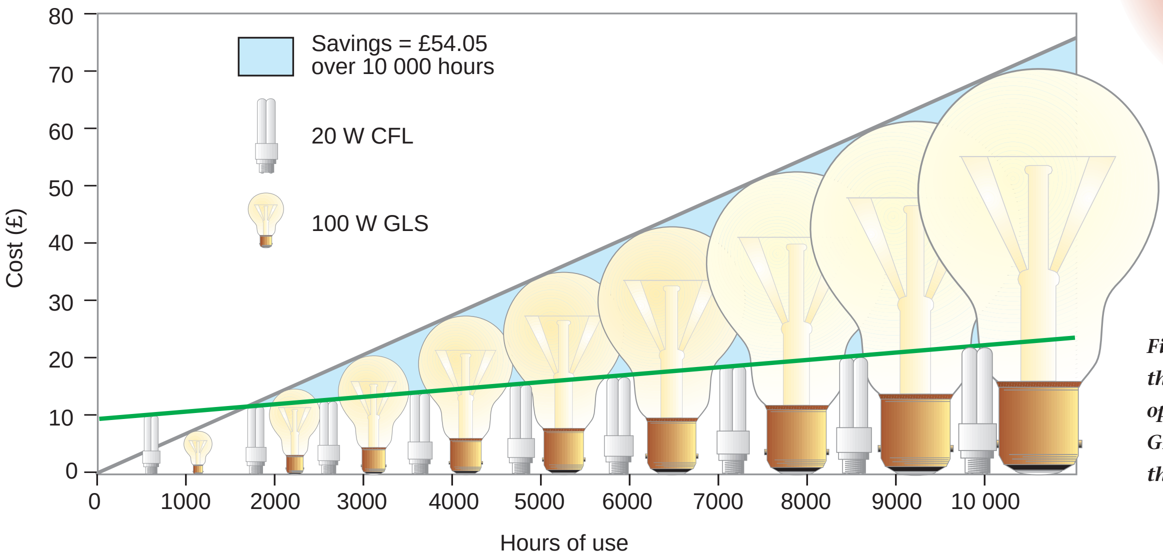

Figure 20 Diagram comparing the total cost (capital and operational) of using a 100 W GLS lamp or a 20 W CFL over the life of the CFL

Note
100 W tungsten filament lamp (GLS) initial output 1330 lumens, cost £0.50, life 1000 hours
20 W compact fluorescent lamp (CFL) initial output 1200 lumens, cost £9.99, life 10 000 hours
Cost of electricity £0.0738 per unit (kWh)

Consideration of costs is a major part of the lighting design procedure. It is important to consider the capital costs together with the operational costs to ensure that an overall economic solution results.

The capital costs include the cost of the design, the equipment (lamps, luminaires and controls) and its installation – both physical and electrical. It also includes commissioning and testing the installation. Allowance must also be made for any builders' work that forms part of the lighting installation. Any other costs that are particular to the design may also need to be included.

The operational costs include the cost of the electricity consumed, which comprises items such as standing charges, maximum demand charges and unit costs. They will also include the cost of the maintenance, which includes cleaning and relamping, and possibly the cost of lamp disposal.

If the two cost elements are not considered together in terms of a life-cycle costing, then a solution which has a low capital cost but a high operational cost could be more costly overall than an installation with a more expensive capital cost but a low operating cost. A conflict of interests may arise when the two costs come from different budgets or different organisations. Here, the designer needs to present a balanced approach.
A simple example is shown in figure 20, comparing the overall costs for using a CFL and an incandescent lamp of similar light output, showing that over £50 can be saved over the life of the CFL.

It is also necessary to consider the lighting costs relative to other building costs. For example, the capital cost of an electric lighting installation for an office is typically about 3-5% of the total cost of the building. In terms of its electricity costs, it can represent as much as 50%, although with good energy-efficient design this can be much lower. The cost of the workforce can represent around 80% of the total operating cost for an office. Consequently any lighting economies made that reduce the performance of the staff could be false economies.

9 DEVELOPING THE LIGHTING DESIGN

The earlier part of this Guide has described the fundamental elements that need to be considered to achieve a successful lighting installation. The next step is to consider the particular lighting requirement and to develop the design for the building in question. This will require close co-operation between members of the design team, particularly the architect, and the client or users of the building. It will be helpful to employ a suitably qualified designer to ensure that the process is carried out effectively.

The designer should start by exploring in detail the purposes for which the building and the individual spaces are to be used. If this is not specified in the brief the client and the architect will need to help assess this requirement.

For a new building, the next step will be to understand the basic architecture and develop the daylighting design. This will need to be done in conjunction with the architect. Most people prefer to live and work in daylit buildings if possible. The reasons for this range from the benefits of contact with the outside, through to the variability of daylight in terms of level and distribution with time. It may also be because of the 'natural' modelling of objects and surfaces provided by the horizontal flow of light through side windows. But lighting is only part of the consideration, and all the other aspects of windows such as their thermal, acoustic and privacy properties will need to be addressed.

Once the daylight design has been determined, attention can be turned to the electric lighting. As a way of ensuring that both the task lighting and the lit appearance of the building are addressed, the designer/architect might find it useful to consider the lighting for the two main zones of the space. These can be defined as the task lighting area(s) and the building lighting area(s), which together form the major part of the normal visual field and are shown diagrammatically, for a typical horizontal task, in figure 8 on page 10.

TASK LIGHTING ZONE

The task lighting requirement has been discussed in some detail in section 3. Essentially it is providing lighting which enables the occupants to carry out their tasks easily and comfortably, and forms a natural element of the interior architecture and its furnishings. The following points need to be considered.

- What are the tasks to be carried out and for how long?
- What is the visual ability of the occupants (eg are the people young, elderly or partially sighted)?
- What is the required task illuminance level and plane of work (horizontal, vertical, etc)?
- What is the required task area illuminance uniformity?
- What is the limiting glare requirement or glare index (direct and reflected glare)?
- What are the lighting colour performance requirements (eg colour rendering and appearance)?
- Is the task area fixed or will there be the need for frequent alterations?
- Are particular lamps or luminaires required (eg hostile environments, etc)?
- What is the requirement for task lighting controls (eg dimmer, daylight and occupancy controls)?
- What are the opportunities for task lighting (eg ceiling, wall, floor, and workstation)?
- Is there a requirement for emergency escape lighting (not covered in this Guide – see reference [1])?
- What is the visual relationship with adjacent areas or rooms?
- What other requirements are pertinent to the task?

BUILDING LIGHTING ZONE

The building lighting requirement has been discussed in section 4 and is about creating a lit scene that is appropriate for the application or tasks, and for the architectural design. It means providing the appropriate degree of visual lightness and visual interest. It will also need to be a natural extension of the interior architecture including the furnishings, as covered in section 5. The following items will need to be considered.

- What is the required lit effect of the building lighting area? Consider main vantage points.
- What is the required sense of visual lightness (ie illuminance, illuminance distribution and reflectance of the building lighting area)?
- What is the required sense of visual interest (ie illuminance variation of the building lighting area)?
- What degree of visual comfort and stimulation is required?
- What building lighting controls will be required (eg time switches, daylight and occupancy controls)?
- What building lighting equipment is required (decorative, concealed, etc)?
- What are the building lighting opportunities (eg architectural details, etc)?
- If emergency lighting is required, can it be combined with other lighting equipment (not covered in this Guide – see reference [1])?
- Are there any other requirements pertinent to the building lighting?

DETAILED DESIGN

Once the lighting design concept has been determined for both the task and the building areas, then the detailed design can commence. It might be that the lighting systems for the two areas are separate, and require different types of equipment, and independent controls. Alternatively, the two elements could be provided from just one system but this will depend on the requirement, the lighting approach proposed and the nature of the building. Whichever approach is used, they will need to be so combined that the overall effect is integrated both in terms of its operation and its appearance.

To achieve the best possible solution the lighting designer and architect will need to work closely together from early in the design period – without this, decisions will be made which will exclude good lighting solutions. It is impractical to assume that because electric lighting is not installed until late in the building period that the lighting design can be delayed or ignored.

It may be that the architect will need to provide architectural opportunities to incorporate the lighting, and if these are planned early in the design process they need not be costly. Because the integration of the lighting with the architecture is so important, it will be necessary to consider the detailed design, for example, how the luminaires will fit into a ceiling or onto a wall, how the cables will be fed to luminaires or controls and how window blinds will be fitted, to name but a few of the issues. It is only by considering all aspects of both the daylighting and the electric lighting together, using properly qualified lighting designers, that a successful solution that works well at every level, including energy efficiency, will result.

Figure 21 This office has been lit to provide good task and building lighting which combines the required task illuminance and glare control with an installation that enhances the overall appearance of the building

EXPLANATION OF TERMS

The Guide makes reference to terms that might not be familiar to all readers, so the following explanations are provided.

LIGHTING UNITS

The ***lumen*** describes the amount of light emitted by a source or received by a surface, eg a 100 W incandescent lamp emits approximately 1200 lumens.

Illuminance – this is the term used to describe the amount of light falling on a surface which can be horizontal, or any other orientation, and is measured in lumens/square metre or lux. It can be the ***average illuminance*** over a particular surface, such as a desk or the display shelves in a shop. ***Maximum illuminance*** or ***minimum illuminance*** is the highest or lowest illuminance on a particular surface. ***Illuminance uniformity*** describes the variation in illuminance across a particular surface, such as a working plane, and is usually described by the ratio of minimum to average illuminance. ***Maintained illuminance*** describes the minimum working illuminance that is required, and is the illuminance at which some element of maintenance needs to occur to avoid the working illuminance becoming too low.

Efficacy – this describes the efficiency at which a lamp converts electricity into light. It relates the total light output of a lamp circuit to the total amount of electricity consumed. It is measured in lumens/Watt. It is important to include all the elements of the circuit that consumes energy and affects light output.

Reflectance – this describes the amount of light that is reflected by a surface relative to the incident light. It is quoted either as a decimal or a percentage. If a surface comprises different reflectance values for parts of a surface, eg a wall with windows, then the reflectance of the whole wall needs to take account of both the individual reflectance values together with their areas to provide an area-weighted reflectance.

The colour performance of a lamp is described by its general ***colour rendering index (Ra)*** which defines its ability to show surface colours accurately. It is described by a number – 100 is considered to be excellent, a value of 80 and above is good, and appropriate for most situations where people are present. Where colour identification is important, a value of 90 or above should be used. The colour appearance of the light from a lamp is described by its ***correlated colour temperature (CCT)*** and defines its appearance in terms of 'warmth' or 'coolness'. For example, a warm-appearance lamp, such as an incandescent lamp, will have a value of around 3000 K, while a lamp which mixes reasonably well with daylight will have a value of 4000 K.

A simple way of describing luminaire efficiency is by its ***light output ratio (LOR)***. This is the ratio of the total luminaire light output relative to the total light output of the bare lamp or lamps. However it takes no account of where the luminaire light output is directed, which in terms of the efficiency of providing a task illuminance will have an effect. In this case the ***utilisation factor*** is required. This is the proportion of the lamp(s) lumen output that reaches the particular plane, eg horizontal working plane, either directly or by reflection. This takes account of the luminaire light output distribution, the size and shape of the room and the room surface reflectances.

THE LIGHTING INSTALLATION

Visual function – this describes the need for the occupants to be able to see to carry out their tasks, efficiently and comfortably. The tasks may be simple or complex depending on the application.

Visual amenity – this relates to the quality of the lit appearance of the environment which can be described in terms of ***visual lightness*** and ***visual interest***. The term 'visual lightness' describes the 'light' appearance of an interior and relates, in particular to the lightness of the room surfaces, particularly the walls and ceiling. To achieve a light appearance it is necessary to use high-reflectance surfaces in combination with direct illuminance. The term 'visual interest' relates to the light distribution. In general people prefer a room to have a measure of non-uniformity in the light pattern (light and shade) which is appropriate for the application. This can be achieved by lighting some areas more than others, particularly visible surfaces such as walls. How this is done will depend on the architectural design and the particular use of the interior.

Task lighting and ***building lighting*** are ways in which the lighting design can be developed for the two main visual areas within the interior. The task lighting area is the area where the occupants carry out their main tasks. The building lighting area includes the main surfaces which surround the task, particularly walls, the surround to work stations and, in large rooms, the ceiling. The task lighting will depend on the particular tasks undertaken and the building lighting will depend on the required visual amenity and the architectural design.

Electric lighting systems can take many forms, and a number have been mentioned which may not be obvious. These include ***downlights***, which are normally fitted into or onto a ceiling and provide a pool of light underneath. They can be combined into a regular array to provide an even illuminance on a horizontal plane, or by placing them next to a wall they can be used to provide vertical illumination. ***Uplights*** can be wall-mounted, floor-standing or suspended from a ceiling and are used to provide light on the ceiling. ***Wall-washing*** luminaires are used to light a wall surface, either to provide a light appearance or to light a wall that is used for display purposes. ***Accent lights*** are used to highlight an area or object.

Daylight-sensing controls incorporate a photocell that monitors the level of light in a particular area and can be arranged to switch electric lights on and/or off depending on the level of daylight. They can also incorporate lamp dimming to enable the electric light to be adjusted to complement the daylight as required. ***Occupancy-sensing controls*** can be used to operate electric lights automatically to ensure that lights are not left on when rooms are unoccupied, and to switch lights on and off when people enter areas such as storerooms or cloakrooms. These controls can either be installed into the building fabric or may be part of the luminaire itself.

REFERENCES AND FURTHER INFORMATION

REFERENCES

[1] ***Chartered Institution of Building Services Engineers.*** 'Code for interior lighting'. CIBSE, London, 1994.

[2] ***Chartered Institution of Building Services Engineers.*** Guidance Note (GN) 4 'Lighting requirements of Building Regulations Part L'. CIBSE, London, 1996.

FURTHER READING

Chartered Institution of Building Services Engineers. CIBSE Lighting Guides (these are available on a number of different applications).

Building Research Establishment Ltd. David Loe and Kevin Mansfield, 'Daylighting in architecture'. BRE, Garston, 1998.

Building Research Establishment Ltd. James Bell and William Burt, 'Designing buildings for daylight'. BRE, Garston, 1995.

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245 Desktop guide to daylighting – for architects

Good Practice Case Study

361 Energy-efficient lighting for housing – exemplars for builders, installers, owners and managers.

SOURCES OF FURTHER INFORMATION

Chartered Institution of Building Services Engineers (CIBSE)
222 Balham High Road
London SW12 9BS
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Electrical Contractors Association (ECA)
ESCA House
34 Palace Court
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Energy Saving Trust (EST)
21 Dartmouth Street
London SW1H 9BP
Tel 020 7222 0101. Fax 020 7654 2444

Institute of Lighting Engineers (ILE)
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International Association of Lighting Designers (IALD)
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Lighting Industry Federation (LIF)
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